Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 36 (2014) 131 – 139

Procedia Computer Science

Complex Adaptive Systems, Publication 4
Cihan H. Dagli, Editor in Chief
Conference Organized by Missouri University of Science and Technology
2014-Philadelphia, PA

Challenges of Governance in Complex Adaptive Systems: A Case Study of U.S. Public Education

Sibel McGee,[a,*] Robert Edson[a]

[a]*Applied Systems Thinking Institutute/Analytic Services Inc., 5275 Leesburg Pike, Falls Church, Virginia, 22041, USA.*

Abstract

Many argue that U.S. public education suffers from inadequacies. Over the years, the U.S. public education enterprise has implemented various response efforts with no major improvements. Approaching U.S. public education as a complex adaptive system, we argue that an accurate characterization of its operation and performance requires holistic assessment of its underlying structures. We identify stakeholders, issues, processes and relationships of this system. We also identify governance practices to explore if they are positioned to manage performance effectively. We map out the dynamics of U.S. public education and link its performance problems to structural properties (particularly governance practices) designed into this system. We conclude that although U.S. public education is a complex adaptive system, it is not governed as such. We discuss how structural properties of this system limit its adaptive capacity and alignment of governance practices with complex system requirements.

Peer-review under responsibility of scientific committee of Missouri University of Science and Technology

Keywords: Systems thinking; public education; complex adaptive systems; governance.

1. Introduction

For the past few decades, many stakeholders including parents, educators and policy makers have frequently noted the shortcomings of American public education. The general unease pertains to low proficiency levels, graduation rates, college readiness and achievement gaps between students of different backgrounds [1]. Additionally, U.S. students' performance consistently lags behind that of students' in other developed countries in international tests [2]. Despite the general consensus on inadequacies, stakeholders neither agree on the root causes

* Corresponding author. Tel.: +00-1-703-416-3342.
Email address: sibel.mcgee@anser.org.

Peer-review under responsibility of scientific committee of Missouri University of Science and Technology
doi:10.1016/j.procs.2014.09.049

of the problem nor on the corresponding set(s) of potential solutions. Previous reform approaches entailed isolated attempts to revise different aspects of the education system (e.g., the curriculum, preschool education, national standards, parental involvement, etc.) with no lasting, system-wide improvement.

Clearly, previous efforts can pinpoint some of the key elements that shape U.S. public education's performance. Yet, they fail to recognize that public education performance is not a direct result of a single element or agent alone (e.g., tests, teachers, etc.), but rather is deeply rooted in the internal structure of the U.S. public education system. The public education system - similar to other social or "human activity systems" [3] - is a complex adaptive system (CAS). As such, its behavior must be reviewed in the dynamic setting in which education elements/agents exist and from whose interactions education outcomes emerge. We need to understand the configuration, structural properties and relationships of this broader system to resolve the most formidable challenge of a CAS: management of its performance towards desired outcomes. It is this broader context of a CAS that shapes behaviors of its stakeholders, conditions governance options, and in turn shapes its performance-related outcomes.

Approaching the U.S. public education system as a case of a CAS, this study begins by discussing key characteristics of CASs and the challenge they pose for governance. Drawing on existing literature, we develop a causal loop diagram of the U.S. public education system, mapping dynamic relationships/interactions between issues, actors and processes. We characterize various forces and the way in which they fail to motivate and mobilize stakeholders toward different (probably more effective) practices that are likely to improve education outcomes. We argue that some of the long-standing structural properties in the U.S. public education system conflict with realities of a CAS. These properties serve to constrain governance options and practices, thereby hindering emergence, self-organization and dynamic adaptation found in effective CASs. To improve performance, policy-makers need to revise the governance structure and align it with public education's mission and requirements as a CAS.

2. Complex adaptive systems: Overview and implications for governance

Before we begin our assessment, it is helpful to briefly discuss CASs in reference to key properties on which many researchers agree. Below we provide these properties along with our understanding of their relationship to the U.S. public education system:

- A CAS is composed of many interacting, intelligent and independent actors [4, 5, p.18]. Local/State/Federal governments, school administrators, teachers, students and parents are the key agents interacting within the U.S. public education system. They act with varying degrees of independence, which may be utilized to serve self-interest, promote the good of the entire system or alternatively exercised to the detriment of the system.
- Complexity in a CAS flows from the "density of causal connectedness" [6, p.9], which manifests itself in the plethora of nonlinear interactions amongst agents/issues. For example, in an education setting, the nature and quality of learning is a result of many variables (e.g., teachers, parents, students, curriculum, school environment, available technology, etc.) interacting together.
- A CAS "ha[s] the capacity of adapting to changed circumstances" [6, p.7]. It evolves in response to agents' interactions, the system's history, and interactions with the environment [5, p.18; 4, p.55]. As a result, "complex adaptive systems have strong tendencies to learn, adapt, and self-organize" [5, p.22]. Standardized tests in the U.S. public school system shifted educational standards. The new standards encouraged search for different teaching/learning practices. While some teachers/schools experimented with creative, more challenging teaching methods, others may have found ways to work around this requirement (e.g., teaching to the test) to ensure high scores in tests without necessarily comprehensive or internalized learning.
- Behavior of CAS agents is an outcome of "physical, psychological or social rules rather than the demands of system dynamics" [5, p.18]. Agents are "goal-driven" and their adaptation to changing conditions is often guided by their desire for goal attainment. Educational performance targets serve as only one of many contributors to teacher performance. For example, teachers likely desire to see their students succeed, achieve a decent living standard, have their peers/communities recognize their efforts and receive rewards for their good performance. Teacher performance is likely to be enhanced by addressing these goals together.

Given the extent of "causal connectedness" in a CAS, controlling and predicting performance is particularly challenging. Below are some key points on CAS governance and their implications for U.S. public education:

- CAS governance should favor influence over control [5, p.18]. Decision-makers of CASs can influence agents' behaviors by creating conditions and decision rules conducive to a CAS' adaptation. Governing practices within the public education system should avoid dictating the behavior of key education agents such as teachers and principals; developing mechanisms that encourage certain behavioral outcomes is likely to be more fruitful.
- Strategies utilized to influence agents' behaviors in a CAS should leverage "natural attractor patterns" and find a way to link them to desired outcomes [7, pp.2-3]. Student performance may be improved by rewards for good performance (e.g., off campus lunch); teacher performance may be promoted by additional (material or immaterial) benefits for achieving desired outcomes.
- CAS governance should avoid subscribing to mechanisms that impose artificial order and resist change [7, pp.1-2]. The U.S. public education system could increase agility by freely adapting or reconfiguring to accommodate changing educational requirements.
- CAS governance should empower rather than restrain local actors [6, pp.7,14]. Such dispersed power should serve to maximize potential benefits from "generative relationships" (i.e., interactions among parts…[that] produce valuable, new and unpredictable capabilities not inherent in any parts acting alone") and free flow of information [7, pp.3-5].The U.S. public education system should afford school administrators, teachers, superintendents and even students and parents authority and influence in its operations. Key stakeholders (e.g., principals, parents) should be allowed sufficient autonomy to act independently ensuring self-interest as well as the system's interests. This is likely to bring about potentially positive emergent outcomes.
- CAS governance can be more effective in managing performance by setting high-level system targets instead of component-level, detailed targets [7, pp.5-6]. The U.S. public education system needs to have system-wide common goals to encourage its agents to collaborate for reaching those system-wide targets. Particularly, targets that ensure quality and consistency across the system (e.g., teacher qualifications, learning standards, etc.) would be beneficial for overall performance of this system.

3. Methodology

This paper follows a systems thinking approach guided by several systems thinking tools and methods, including the Conceptagon [8] and Causal Loop Diagrams (CLDs) [9]. We began our study with an extensive problem definition task, exploring manifestations of poor performance of the U.S. public education system. We reviewed the education literature to characterize the U.S. public education system as a whole, recognizing the relationships/interactions between its components/agents; identified its actors (stakeholders) and their perspectives (interests, desires, and requirements) to gain insights into reasons for the way they behave; defined current governance practices and control means (i.e., policies, regulations), decision-making authorities (e.g., resource determination/allocation, staffing, etc.); assessed their alignment with requirements and challenges of CASs; and portrayed the underlying feedback structures to explore critical pathways through which system-level performance and the associated problems emerge. Due to space constraints, some of the steps are omitted here. In this paper, our focus is on exploring causal relations of US public education actors/issues/processes and how these relationships are impacted and conditioned by various governance practices.

Data for this study were collected from open source literature such as academic studies and analyses, news items, national/international non-governmental organization reports and government publications and statistics.

4. A brief review of the US public education literature: Key elements and relationships

The first step to develop a CLD of this complex problem space is to review the literature to identify key elements (i.e., issues, activities and players) and relationships that influence education outcomes. The quality, recruitment/dismissal and compensation of teachers, school funding, school choice, school leadership and national standards are often identified as key variables of public education. Nonetheless, education literature does not always present clear consensus on how these variables and actors interact. As such, some relationships are still contested.

Many studies conclude that teacher quality and school leadership explain significant variation in student performance, with the former being the most important in-school factor [10, p.5; 11]. Researchers are divided on the

nature and measurement of characteristics of a high quality teacher [12]. Characteristics covered in different studies include "preparation in both pedagogic and subject content, credentials, experience, and [teachers'] test scores" [13].

Studies conclude that advanced academic degrees are associated with increased student learning (especially in math and science) [10, p.6]. Also, academic degrees in subject content that a teacher is asked to teach influences student achievement [14, 15]. Although studies have been inconclusive about whether various forms of certification or licensure (alternative route, emergency, subject-specific) affect student performance, teacher certification in math has some evidential support for higher student learning [10, p.7]. Yet, minimum qualifications are often waived when teacher shortages appear [11, p.7]. Teacher experience is also found to increase student achievement. [13, 16] Another factor that the previous studies tied to teacher quality is quality of the teacher pool. A key report found that those high school graduates with intentions of going into an education field "scored bottom third in their SATs [and] their combined scores in mathematics and reading came in at 57 points below the national average" [11, p.12]. Studies confirm that "teachers' own scores on college-entrance and certification exams positively relate to greater student achievement" [10, p.9]. The quality of teaching programs also matter. Yet, a recent report assessed 608 teaching programs on a four star scale and concluded that "less than 10 percent… earn[ed] three stars or more" [17].

Teacher hiring, dismissal and compensation are some of the most critical dynamics in public education. Attracting qualified teachers requires incentives competitive with other professional jobs [11, p.14]. Although there is no general consensus in the literature, some studies including those that rely on international comparison often show a link between high salaries and teacher quality [11, p.11; 18; 19]. Teacher pay in many States still relies on uniform pay schedules (valuing years of experience) rather than education outcomes. Although competitive pay may attract quality teachers, studies note other factors to retain quality teachers such as supportive and engaged principals, collaborative working environment and sufficient resources [10, p.16-18;20; 21].

Once a teacher is hired, identified weaknesses can be addressed by professional development programs [9]. For a long time teacher evaluations relied on only the principal's classroom observations. Although fiercely debated, many states have recently moved (largely due to Federal programs such as No Child Left Behind waivers, Race to the Top and Teacher Incentive Fund) to tie student achievement (as evidenced by their scores in standardized tests) to teachers' evaluations [22]. Yet, contracts negotiated with teacher unions still make termination of even persistently ineffective teachers an extremely costly and time consuming endeavor [23, 24].

U.S. public education funding is provided by a combination of local, state and federal sources. The majority of total funds comes from local tax revenues (43.4) and state sources (44.1 percent) while federal sources- funds that often attempt to address discrepancies across schools (e.g., Title 1 funds to high poverty schools, grants to states, improving teacher quality grants, English language acquisition, etc.) account for only 12.5 percent [25]. As such, school budgets hinge heavily on average household income in a school district. Notwithstanding few exceptional states, this results in large funding differences between schools [26, 27]. In the absence of public school choice, implications are huge for students in low-income districts. Many studies confirm that disadvantaged (low-income and minority) students "tend to have less-effective teachers as signaled by such characteristics as: lack of certification in the subjects they are teaching; failure to pass certification exams; matriculation at the least competitive undergraduate institutions; and poor performance in prior academic settings" [10, p.35].Although teacher quality and general school context [10, p.16; 21] explains some variation in student performance, out of school factors also influence student performance such as family background and education and poverty level [28].

5. Mapping dynamics of the U.S. public education: Observations and discussions

We have started our assessment with the recognition that public education is a CAS. We cannot begin to understand the behavior of this system without a dynamic characterization of its structure. Reflecting our understanding of the literature and education dynamics in general, we have developed the CLD seen in Figure 2. A review of this CLD provides informative insights. Education outcomes emerge as a result of the interaction over time of a multitude of elements—actors (parents, students, teachers, peers, administrators, etc.), issues (household income, school budget, curriculum, standards, teacher compensation, teacher quality, etc.), and processes (teaching, learning, staffing, assessing, etc.). Some of these actors and issues are not necessarily endogenous to the education system (e.g., teacher unions, district income, higher education institutions, industry, etc.), even though they strongly

affect educational outcomes. Actors of the education system, who mediate system interactions, behave in light of their perceptions and needs. Combined, all this provides insights into why the system behaves the way it does.

The education problem space is composed of multiple domains to include the school district characteristics (e.g., household demographics, etc.), education standards, school choice, school funding and spending, school autonomy (teacher pay, hiring and dismissal practices, etc.), quality of teacher candidates and teacher standards, teacher quality and accountability, K-12 student performance and coordination with higher education/industry. These domains are interrelated in many ways. For example, the characteristics of a school district impact many aspects of educational experience in the respective schools. Specifically, school requirements and resources are closely linked in a district. The amount of funds a particular school needs hinge on its requirements. Yet, both of these variables are to a great extent determined by a third variable: average household income in a district. Low-income districts have schools with the greatest requirements since their students often need additional support due to a number of potential reasons (i.e., low parental involvement, distractions from learning, and barriers associated with minority background, etc.).

This predicament is widely noted in education circles; yet, how its effects cascade into various domains that may otherwise seem unassociated is readily visible in the CLD. For example, the need for quality teachers and supplemental programs are likely to go up with the number of students in need of additional support. However, low-income districts have a harder time attracting and retaining high-quality teachers not only because of low pay, but potentially also because of the low overall desirability of these schools [29]. As such, unless robust standards on teacher qualifications are implemented, schools in low-income districts are likely to have a higher percentage of ineffective teachers compared to high-income districts.

The CLD portrays K-12 student performance as a function of two elements- test scores and the ability to apply knowledge (versus learning at face value), both of which rely on student learning. Student learning, in turn, depends on complex interactions of many variables (Figure 1). It increases with curriculum quality, support services, parental involvement, school quality, student engagement and intelligence and teacher quality. The ratio of disadvantaged students decreases learning due to negative peer effects [30, 31].

A critical part of the education problem space is teacher quality and the nature of accountability procedures in place. The CLD shows that teacher quality is a function of the standards met by teachers hired and in circulation (impacted by the quality of teacher candidate pool and teacher qualification /certification standards), teacher experience, accountability, and motivation. Performance-based accountability practices would generate both positive and negative results for teachers. A teacher's performance may have implications for differential pay benefits or job security. In reality, all of these relationships are meaningful if school administrators have credible decision-making powers.

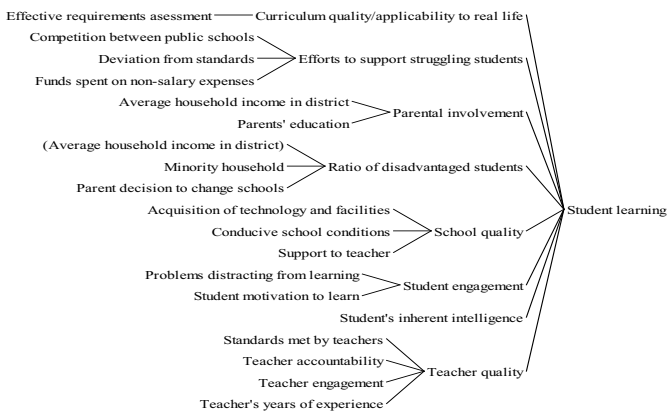

Figure 1: Student Learning

5.1. Problem Assessment

As previously discussed, this system's behavior emerges through multiple feedbacks dispersed across several domains. As such, rather than a clearly bounded, singular problem, the public education space may be better characterized by a series of problem areas. Existing studies and stakeholder testimonies indicate that identification of each problem area in its own right is not uncommon. Yet, this paper contributes to the discussion by arguing that these problem-areas are interrelated (as portrayed by the CLD) reinforcing one another's negative effects on the system outcome (i.e., K-12 performance). Further, they are largely caused by the underlying structure of the system that governs and regulates its operation and behavior.

Although U.S. public education is a CAS, it is not treated or governed as such. Structural properties (especially governing rules/practices) of the system are not aligned with CAS requirements. Let us briefly explain this by capturing each problem and linking it to the underlying structure of the US public education system.

Limited remediation of student disadvantages: As seen in the CLD, students' learning results from a complex

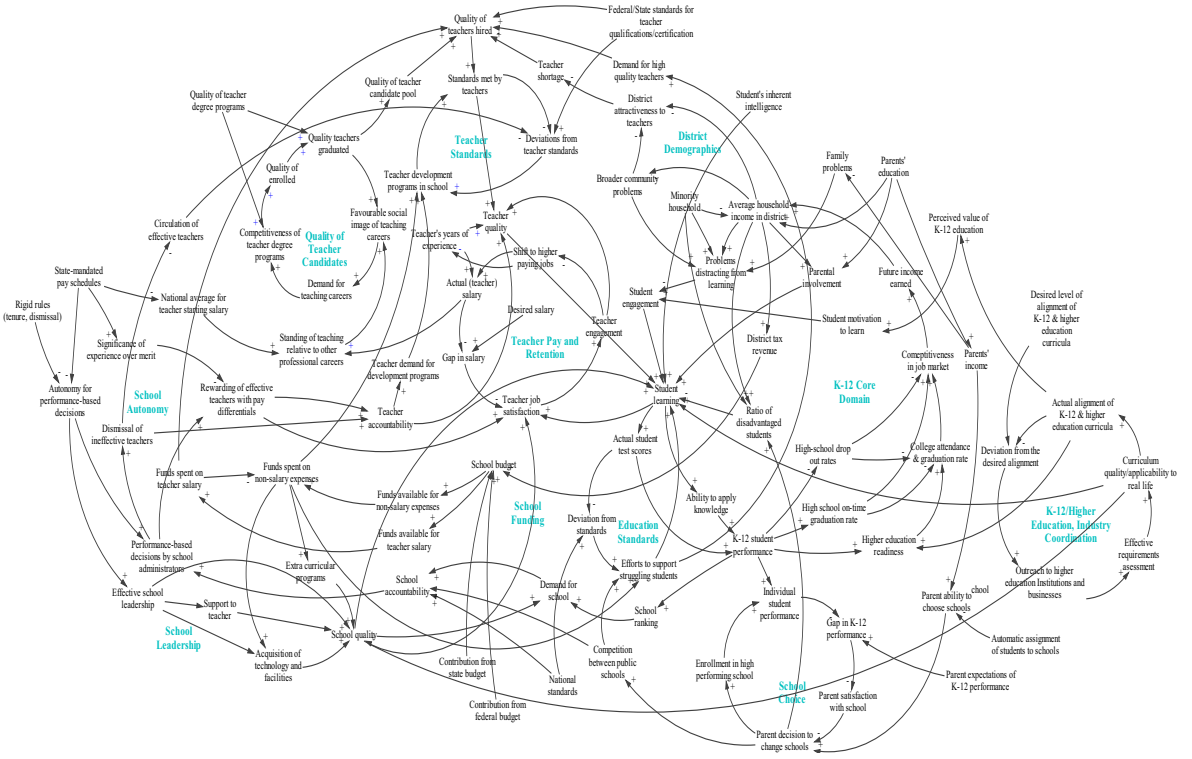

Figure 2: CLD of US Public Education Problem Space

interplay of many variables (e.g., inherent intelligence, parental involvement, and student engagement as impacted by problems associated with family environment, household income, and the broader community problems, etc.). Although causes of such learning disruptions are not endogenous to the education system, schools' ability to offset the adverse effects is critical. The desire of disadvantaged students/ parents to overcome such handicaps could be a crucial lever for schools. Better information flow between students/parents/community (e.g., community outreach groups, libraries, etc.) and schools/school staff (e.g., teachers, principals, counselors, social workers, etc.) through effective interface arrangements provide structural motivators for students to do better in school. For example, parental involvement and positive role models can encourage students to do better at school. Currently, the presence and quality of such interface platforms (e.g., institutionalized continuous feedback) vary across localities. Similarly, some of the aforementioned stakeholders are not readily available in all schools.

Fiscal constraints of public schools: Once in the school environment, a student's performance is largely dependent upon (in addition to his/her capability to learn) that school's ability to provide a compelling learning environment, which can be conceptualized as a combination of a school's general quality (e.g., leadership, facilities, technology, curriculum, non-curricular programs, etc.) and the quality of its teachers. Both of these elements- at least in part- depend on a school's resources. Public schools are largely funded through local resources (mainly tax revenues), resulting in schools with significantly unequal resources across and within states. Schools with financial resources can update facilities, acquire new technology, develop strong curriculum, implement student/teacher support programs, and more importantly can afford high quality teachers. Schools in low-income districts may not be able to afford most or any of these. Current budget determination/allocation practices- significant elements of system governance- tie public education providers' budget largely to public education consumers' resources, limiting public schools' ability to customize their budget according to local needs. This lowers public schools' ability to adapt to

changing requirements. Moreover, these practices, many studies note, are likely to hurt the low-income and minority students disproportionately. This governing principle may be serving as a structural obstacle to ensuring equity in access to quality public education- a condition that by definition should hold for any public good [32].

Lack of national standards for teacher requirements: In addition to public schools' financial constraints and other variables, quality of the teachers hired is influenced by quality of the teacher candidate pool. The latter is determined by the strength of teacher degree programs as well as the type of students who enroll in such programs. Both are beyond the K-12 public education system's direct control. Yet, determining and issuing standards- another governance function in a system- is one way through which the public education system could control the quality of teachers in circulation. Currently, requirements for teacher certification present considerable variation across States; while some states uphold rigid standards (e.g., a degree in subject being taught), others subscribe to more relaxed standards (e.g., allowing teachers to teach beyond their subject areas) [11, p.17]. The CAS research indicates that CAS performance is handicapped by micromanagement strategies and enhanced by high level target/standard setting. Teacher qualifications may serve as system-wide standard that could enhance consistency in teacher quality.

Rigid rules for teacher performance management: In addition to fiscal constraints, a school's ability to address teacher performance deficiency is impacted by current policy and legal constraints. Uniform pay schedules enacted by states as well as job security privileges attained by teacher unions serve to limit school autonomy to reward or punish teacher performance [33]. For example, deterred by the time and cost required to dismiss a teacher, school administrators often avoid firing ineffective teachers. Standard pay systems and unconditional job security remove two of the potential structural motivators for teachers to invest heavily in professional growth. Such policy and legal constraints may be reducing teacher accountability.

Inadequate accountability of schools: The concept of accountability covers presence of rewards/sanctions and credible implementation. Existing governance practices in U.S. public education bar exercise of traditional accountability. The current predominant practice of student allocation to neighborhood schools- a structural property of the U.S. public education system- reduces school accountability. Unlike affluent parents (who may move or simply switch to a private school), parents without financial means are forced to send their children to the designated schools. As commonly noted, this practice is likely to hurt low-income and minority students disproportionately. Moreover, the lack of school choice allows government-run schools to largely operate without sufficient competition [32]. Empowering parents with public school choice would reduce school monopoly over students in a district, introducing strong incentives for schools to subscribe to high standards for all students. The current practice may deprive public schools of a critical feedback channel (by reducing effective flow of information on school satisfaction, school enrollment/withdrawal, etc.), curbing their ability to learn and restructure for better performance. Yet, unless struggling schools are provided supplementary funds to improve, successful schools are bound to be overwhelmed while low-performing students in failing schools are left to deteriorate (as high-achievers leave) [30].

Lack of coordination between stakeholders of K-12 education, higher education and businesses: The lack of institutionalized and regular feedback channels between K-12 educators on the one hand and representatives of the higher education and industry on the other create discrepancy in expectations pertaining to public education outcomes. While the requirements of a globalized competitive economy are more immediate to higher education and industry sectors, K-12 stakeholders operate in an environment that is more removed from this dynamic world. The disconnect between these two worlds may have many potential ramifications, including low student enthusiasm to internalize K-12 curriculum, missed opportunities to strengthen K-12 curriculum, and inefficient use of limited resources as a result of the frequent need for remedial education during higher education years.

6. Summary

Insights from CAS research indicate that forcing these systems to resemble simple systems is not the solution. Trying to manage such systems by introducing artificial order and uniformity may paralyze the system by handicapping its natural ability to learn and innovate. Researchers suggest establishing high level targets and allowing autonomy and innovation at the lower levels [7, p.5-7].

Our assessment shows that although the U.S. public education system is clearly a case of a CAS, its governance is not properly aligned with the requirements of such a system. Its current problems can at least partly be explained by the way this system is configured and governed. While the U.S. public education system does not establish

sufficient system-wide targets, sub-system level behavior and operation is significantly constrained with long-standing governing rules and practices. Some of the systemic constraints, which make this system more uniform (e.g., funding of public schools through local taxes), orderly (e.g., uniform pay scales, tenure rules), and predictable (e.g., teacher job security, school monopoly over students), appear to have suppressed the public education system's key qualities as a CAS, by reducing, inadvertently, the flow of essential information, removing key incentives and deterrents (e.g., differential pay and potential to lose one's job), and hindering dynamic feedback of interactions as well as the learning process that follows. The public education system may benefit from: providing high-level system targets (e.g., recently introduced national standards, teacher qualifications, acceptable public school and teacher evaluations, etc.), enhancing flexibility in key processes (e.g., funding customized to student needs, school choice, etc.), increasing local agents' autonomy for implementing (both positive and negative) accountability consequences (e.g., differential pay and dismissal decisions, school choice, etc.), allowing innovative practices to enhance teaching and learning, and encouraging stakeholder interaction and information flow (e.g., teacher/school evaluations, collaboration between K-12 and higher education/industry).

This study also shows that public education performance emerges out of many actors' and issues' interaction across different domains. It is not surprising that the education system has not seen system-wide improvements from piecemeal policy interventions in individual domains. Addressing performance of the education system requires consideration of the "whole" system and simultaneous engagement in all domains, in recognition of nonlinear feedbacks of cross-cutting issues, actors, and processes.

Acknowledgements

The authors thank Jaime Frittman, Kristen Klein and Samantha Hammond for review and helpful suggestions.

7. References

1. Aud, S., Hussar, W., Johnson, F., Kena, G., Roth, E., Manning, E., Wang, X., and Zhang, J.*The Condition of Education 2012* (NCES 2012-045). U.S. Department of Education, National Center for Education Statistics. Washington, DC., 2012 http://nces.ed.gov/pubsearch, (accessed March 25, 2014); Chapman, C., Laird, J., Ifill, N., and KewalRamani, A.*Trends in High School Dropout and Completion Rates in the United States: 1972–2009* (NCES 2012-006). U.S. Department of Education. Washington, DC: National Center for Education Statistics; 2011. http://nces.ed.gov/pubsearch, (accessed on March 15, 2014); ACT. *The Condition of College and Career Readiness 2011*. Washington, DC., http://www.act.org/research/policymakers/cccr11/pdf/ConditionofCollegeandCareerReadiness2011.pdf (accessed August 10, 2014).

2. Kelly, D., Xie, H., Nord, C.W., Jenkins, F., Chan, J.Y., and Kastberg, D. *Performance of U.S. 15-Year-Old Students in Mathematics, Science, and Reading Literacy in an International Context: First Look at PISA 2012* (NCES 2014-024). U.S. Department of Education. Washington, DC: National Center for Education Statistics; 2013. http://nces.ed.gov/pubsearch (accessed August 15, 2014).

3. Checkland, P. *Systems Thinking, System Practice*. New York: John Wiley & Sons, Ltd; 1999.

4. Chapman, J. *System Failure: Why governments must learn to think differently* (2nd ed.). London: Demos; 2004, p.51-63. http://www.demos.co.uk/files/systemfailure2.pdf, (accessed February 9, 2014)

5. Rouse, W.B. "Health Care as a Complex Adaptive System: Implications for Design and Management." T*he Bridge, National Academy of Engineering*, 2008; 38(1), http://ti.gatech.edu/docs/Rouse%20NAEBridge2008%20HealthcareComplexity.pdf, (accessed April 10 2014).

6. Stark, B. "A Case Study of Complex Adaptive Systems Theory: Sustainable Global Governance" *Research Paper*, 2009:5, University of Ljubljana, http://www.wisdom.at/Publikation/pdf/RiskBerichte/RRR_BStark_SustainableGlobal_09.pdf, (accessed on February 19, 2014).

7. Plsek, P. "Why Won't the NHS Do as It's Told and What Might We Do About It?" *Leading Edge*, London: NHS Confederation; 2001. http://c.ymcdn.com/sites/www.plexusinstitute.org/resource/collection/6528ED29-9907-4BC7-8D008DC907679FED/Leading_Edge_NHS_Confederation_No._01.pdf, (accessed March 10, 2014).

8. Boardman, J.T., Sauser, B.J., John, L., and Edson, R. The Conceptagon: A Framework for Systems Thinking and Systems Practice. *IEEE International Conference on Systems, Man, and Cybernetics*, San Antonio, TX; October 12-14, 2009.

9. Sterman, J.D. *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Boston: Irwin McGraw-Hill; 2000, p. 137-190.

10. Hightower, A.M., Delgado, R.C., Lloyd, S.C., Wittenstein, R., Sellers, K. and Swanson, C.B.. *Improving Student Learning by Supporting Quality Teaching: Key Issues, Effective Strategies.* Editorial Projects in Education, Inc.; December 2011. http://www.edweek.org/media/eperc_qualityteaching_12.11.pdf (accessed July 18, 2014)

11. Tucker, M.S. *Standing on the Shoulders of Giants: An American Agenda for Education Reform*. National Centre on Education and the Economy; 2011. http://www.ncee.org/wp-content/uploads/2011/05/Standing-on-the-Shoulders-of-Giants-An-American-Agenda-for-Education-

Reform.pdf, (accessed May 30, 2014).

12. National Science Board. *Elementary and Secondary Education: Teacher Quality.* National Science Foundation, Division of Science Resources Statistics Science and Engineering Indicators 2004, Arlington, VA (NSB 04-01). http://www.nsf.gov/statistics/seind04/c1/c1s5.htm, (accessed July 25, 2014).

13. Rice, J.K. *Teacher Quality: Understanding the Effectiveness of Teacher Attributes*, Economic Policy Institute; 2003. http://www.epi.org/publication/books_teacher_quality_execsum_intro/, (accessed July 18, 2014).

14. Ingersoll, R.M. The Problem of Underqualified Teachers in American Secondary Schools, *Educational Researcher* 1999; 28(2). http://repository.upenn.edu/cgi/viewcontent.cgi?article=1139&context=gse_pubs, (accessed on July 31, 2014).

15. Ingersoll, R.M. *Out-of-Field Teaching, Educational Inequality, and the Organization of Schools: An Exploratory Analysis.* Seattle: University of Washington, Center for the Study of Teaching and Policy; 2002. http://www.cal.literacy.org/sites/default/files/researchreport/796_outoffield-ri-01-2002.pdf, (accessed July 25, 2014).

16. Rivkin, S.G., Hanushek, E.A. and John F.K. "Teachers, Schools, and Academic Achievement" *Econometrica*, March 2005; 73(2): p. 417–458. http://www.econ.ucsb.edu/~jon/Econ230C/HanushekRivkin.pdf, (accessed July 10, 2014).

17. Greenberg, J., Mckee, A., and Walsh K. *Teacher Prep Review: A Review of the Nation's Teacher Preparation Programs*, National Council on Teacher Quality, Washington, DC.; December 2013. http://www.nctq.org/dmsView/Teacher_Prep_Review_2013_Report?bcsi-ac61c0992d4f18ed2f=216FC6A200000002fz0atQ5fjo4fjehrkCqzrsqaMXBlUwAAAgAAANkiIAKEAwAALQIAAHo8AgA=, (accessed July 28, 2014).

18. Dolton, P. and Marcenaro-Gutierrez, O.D. "If You Pay Peanuts Do You Get Monkeys? A Cross-Country Analysis of Teacher Pay and Pupil Performance" *Economic Policy*, January 2011; 26(65): p. 5-55

19. Loeb, S., and Page, M. "Examining the Link between Teacher Wages and Student Outcomes: The Importance of Alternative Labor Market Opportunities and Non-pecuniary Variation." *Review of Economics and Statistics*; 2000; 82(3), p. 393-408.

20. Wilson, S. Teacher Quality, Washington, DC: National Academy of Education; 2009. http://files.eric.ed.gov/fulltext/ED531145.pdf, (accessed July 25, 2014).

21. Gordon, G. *School Leadership Linked to Engagement and Student Achievement.* Washington DC: Gallup; 2013. http://www.gallup.com/file/strategicconsulting/163520/School%20Leadership%20Linked%20to%20Engagement.pdf, (accessed July 30, 2014).

22. Hull, J. *Trends in Teacher Evaluation: How States are Measuring Teacher Performance*. Center for Public Education; October 2013. http://www.centerforpubliceducation.org/gm-node/2408.aspx, (accessed July 21, 2014).

23. Thomas, E. "Why We Must Fire Bad Teachers." *Newsweek,* 2010. http://www.thedailybeast.com/newsweek/2010/03/05/why-we-must-fire-bad-teachers.html, (accessed March 16, 2014).

24. Eltman, F. "Firing Tenured Teachers is not just Difficult: It Costs You," *Associated Press/ USA Today*; June 30, 2008. http://usatoday30.usatoday.com/news/education/2008-06-30-teacher-tenure-costs_N.htm, (accessed May 30, 2014).

25. Cornman, S.Q. *Revenues and Expenditures for Public Elementary and Secondary Education: School Year 2010–11 (Fiscal Year 2011)* (NCES 2013-342). U.S. Department of Education. Washington, DC: National Center for Education Statistics; 2013. http://nces.ed.gov/pubsearch, (accessed July 28, 2014).

26. Baker, B.D., Sciarra, D.G. and Danielle F. *Is School Funding Fair: A National Report Card*. Education Law Center; 2010. http://www. schoolfundingfairness.org/National_Report_Card.pdf , (accessed July 23, 2014)

27. US Department of Education, *For Each and Every Child—A Strategy for Education Equity and Excellence*, Washington, D.C.; 2013, http://www2.ed.gov/about/bdscomm/list/eec/equity-excellence-commission-report.pdf, (accessed July 20, 2014).

28. Editorial Projects in Education Research Center. Issues A-Z: Teacher Quality. *Education Week*; 2011, July 8. http://www.edweek.org/ew/issues/teacher-quality/, (accessed July 18, 2014).

29. Adamson, F. and Darling-Hammond, L. *Speaking of Salaries: What it will Take to Have Qualified Effective Teachers In All Communities*, Center for American Progress; May 20, 2011. http://www.americanprogress.org/wp-content/uploads/issues/2011/05/pdf/teacher_salary.pdf, (accessed May 30, 2014).

30. Hoxby, C. "The Power of Peers: How does the Makeup of a Classroom Influence Achievement?" *Education Next*, 2002; 2 (2). http://educationnext.org/the-power-of-peers/, (accessed July 30, 2014)

31. "Using a Complex Systems Approach to Study Educational Policy" McCormick School of Engineering; ND. http://www.mccormick.northwestern.edu/news/articles/archive/2009-2012/article_766.html, (accessed July 29, 2014).

32. Shaw, J. "Education: A Bad Public Good?" *The Independent Review: A Journal of Political Economy*; Fall 2010. http://www.independent.org/publications/tir/article.asp?a=804, (accessed March 22, 2014).

33. Consortium for Policy Research in Education. *Single Salary Schedule*; ND. http://cpre.wceruw.org/tcomp/general/singlesalary.php, (accessed May 30, 2014).